



CD accelerator R&D activities

CD capabilities [expertise] for accelerator R&D:

- .DAQ (hardware & software engineering) & detectors
- .Data storage and management
- .Data analysis & analysis tools
- .Computing & computation infrastructure
- .Modeling and computational physics
- ☐ significant experience in providing support and infrastructure for large R&D projects

So, *perhaps* we could have another discussion(s) on some of



An example...

The Electronic Systems Engineering section of CD has over 10 years of experience with data acquisition system design, upgrades and support in HEP collider and fixed target environments. The most recent major installation is the **CDF silicon DAQ**. For this system, designed, prototyping, production and final testing was done or supervised at ESE. Current projects are small DAQ upgrades, a large DAQ and trigger system and high speed network fabrics. Over the past five years the section has expanded its efforts closer to the sensors with R&D work on front end readout technology and interconnects for planned future experiments at FNAL. Also, the section is **currently consulting with the Beams Division on instrumentation designs and upgrades for several of the accelerator complex systems.**



Accelerator modeling in CD

- Relevant expertise
 - Particle-particle and particle matter interactions
 - High-fidelity parallel computing
 - Analysis tools development and use
 - Experience and tradition in the “modeling -> design -> experiment-> data comparison” paradigm
 - and since R&D is also the means to do it: code distribution, maintenance & documentation tools
- CD involvement in beam physics
 - 2 successful examples: ionization cooling, space-charge in rings



Ionization Cooling Project

- An ideal example of relevance of the (mostly) HEP centric expertise of the CD simulation group
 - Both the physics but also the structure of the project: new concepts, lots of ideas -> **code validation, results verification a must!**
- Timeline (compressed): 1996 (end of 1995?) **development of G3 simulation tools starts** (~1FTE); end of 1996 (~2FTE) have the **ability to model "conventional" designs based either on solenoids or on Li lenses**; 1998 (3FTE+student) **switch to G4** (long term planning...); 2002 involvement is reduced to only supporting G4 beam tools
- Results: memos ~20, PAC contributions, major participants of the **2 NuFACT feasibility studies and muon collider design status paper**



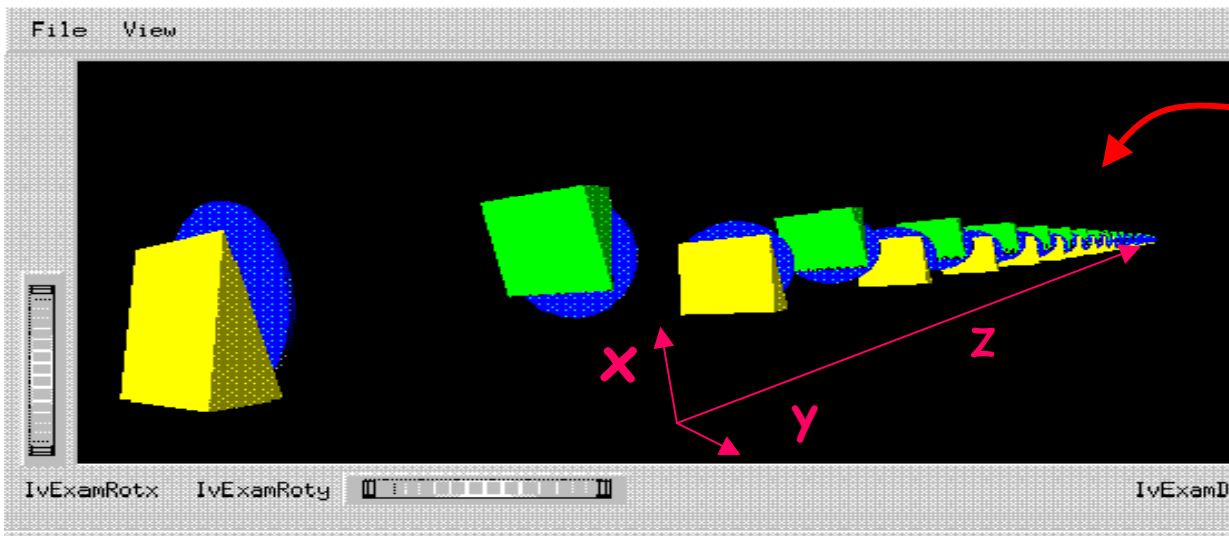
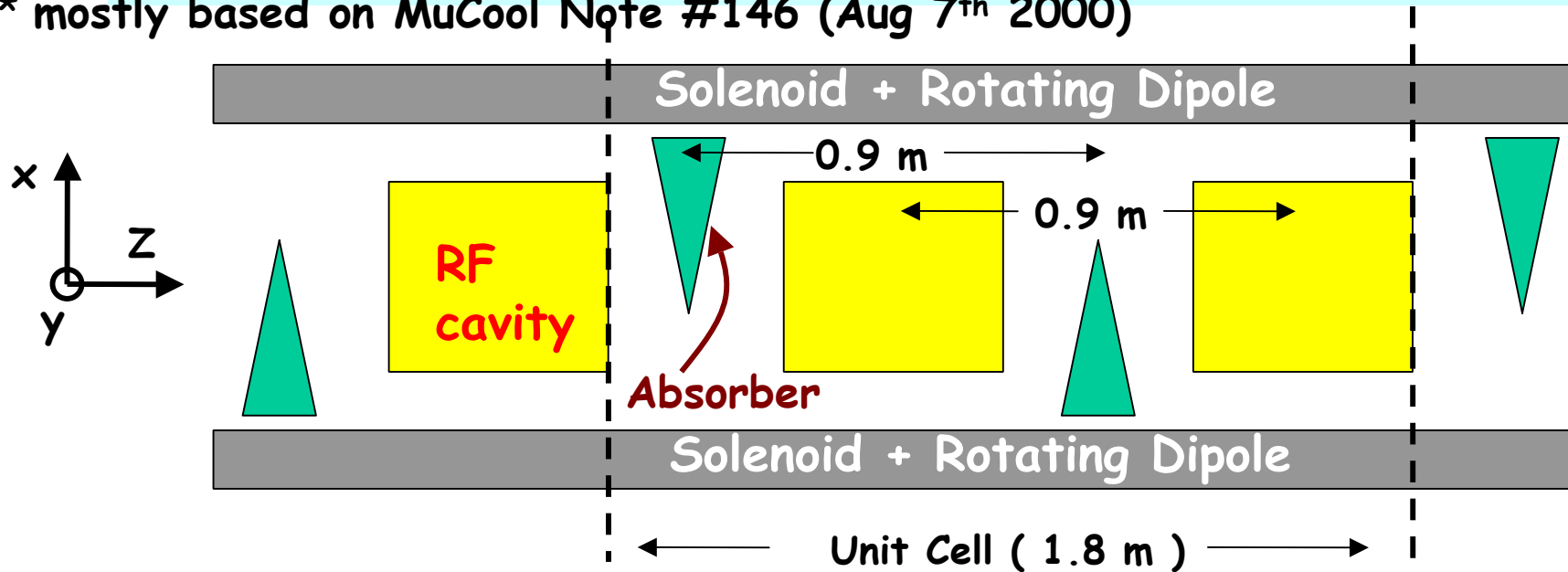
<http://www-pat.fnal.gov/muSim/instruct.html>

<http://cepa.fnal.gov/CPD/geant4/>



Geometry of the Helical Channel*

* mostly based on MuCool Note #146 (Aug 7th 2000)



GEANT4 visualization
(Open Inventor)

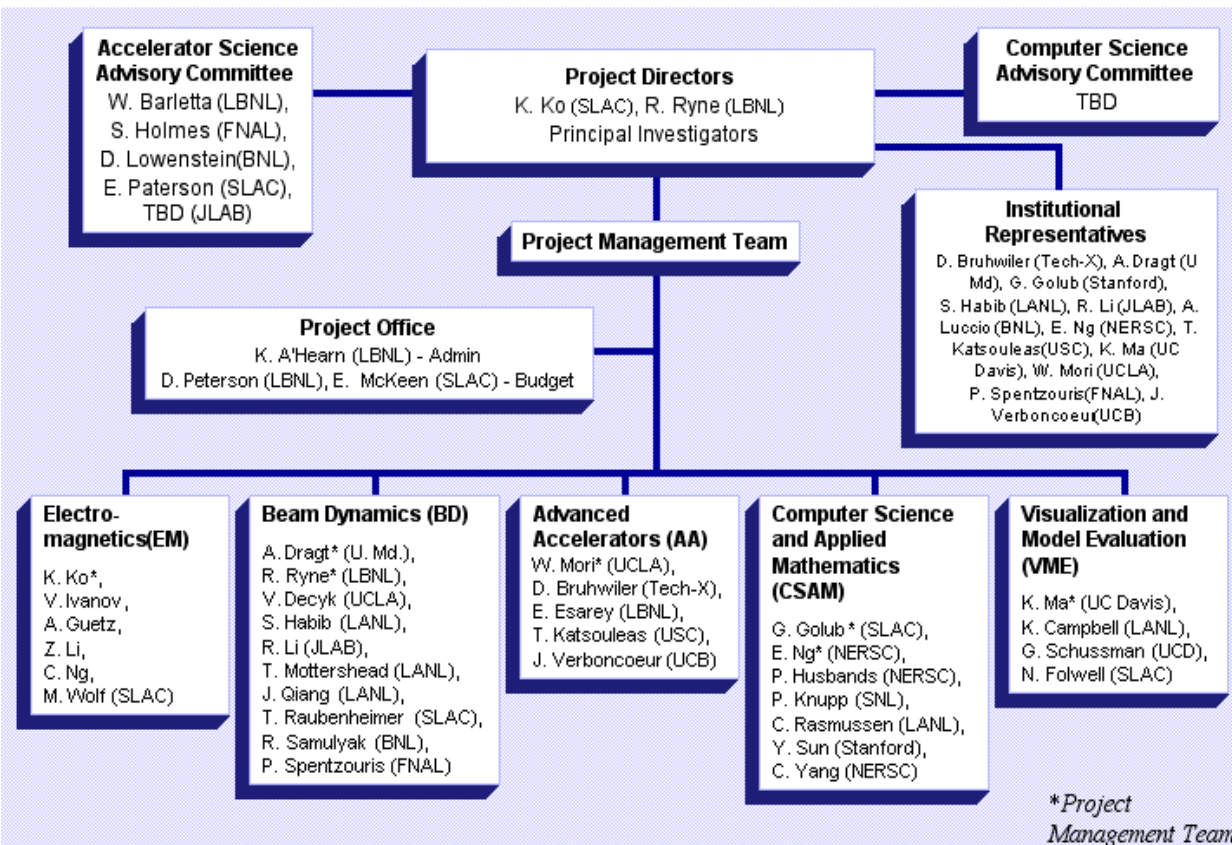
(the blue disks are idealized
RF cavities)

40 cells long
(72 m)



The Συνεργεια Project

SciDAC Accelerator Modeling Project Org Chart
August 2001

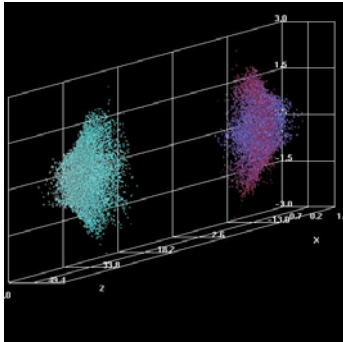


Members of a multi-Institution Collaboration. The charge : develop **the next generation of parallel computing beam dynamics and accelerator modeling tools**

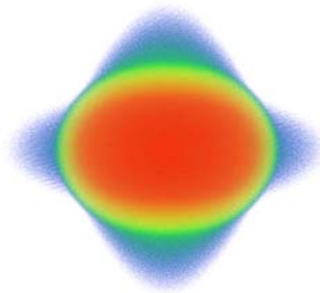
Project funded by the SciDAC DOE program:
\$3M in years; FNAL \$.35M



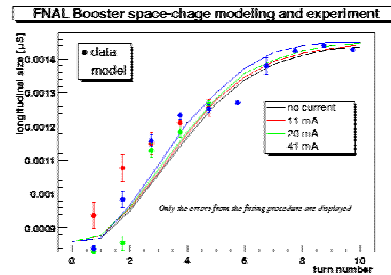
Accelerator Modeling Collaboration



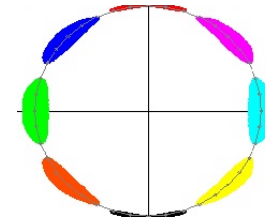
LBNL
Beam-beam modeling,
space charge in linacs &
rings, parallel Poisson
solvers, collisions



UC Davis
Visualization,
multi-resolution
techniques



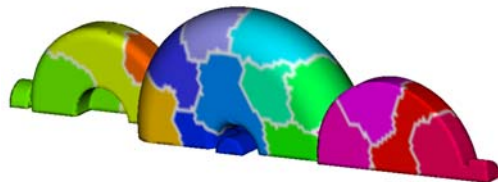
FNAL
Software Integration, Lie
methods, space charge in
rings, FNAL Booster
sim/expt



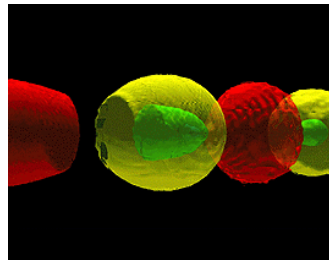
BNL
Wakefield effects,
Space charge in rings,
BNL Booster
simulation

$$M = e^{if_2} e^{if_3} e^{if_4} \dots$$

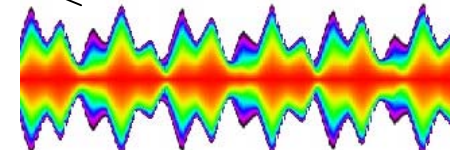
$N = A^{-1} M A$
U. Maryland
Lie Methods in
Accelerator
Physics, MaryLie



SLAC
Electromagnetic component
modeling



UCLA
Parallel PIC
Frameworks

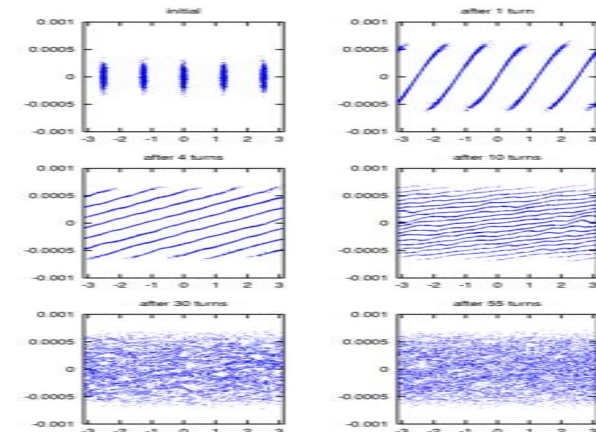
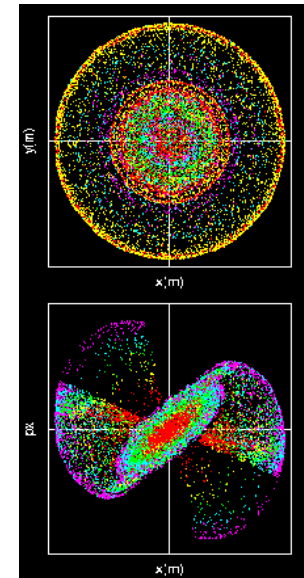


LANL
High order optics,
beam expts, collisions,
multi-language
support, statistical
methods



Parallel Beam Dynamics Timeline

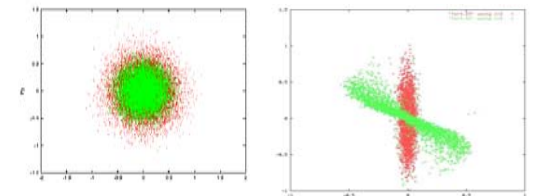
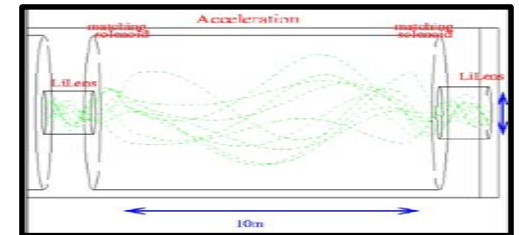
- Roots in 1980s: Lie methods
and early 1990s: LANL-funded PIC code development
 - 2D parallel PIC
- Mid 1990s: DOE Grand Challenge
 - LANL/SLAC/Stanford/UCLA
 - developed **Linac** code (**IMPACT**)
 - 3D space charge, introduce particle manager concepts
- 1999: DOE/HENP bridge funding to SciDAC project
 - added LBNL, **FNAL** {space-charge in ionization cooling channels}, BNL and Jlab
- 2001: **SciDAC Project**
 - Add modeling of high intensity beams in circular machines
 - Additional physics (beam-beam, wakes, collisions,...)
 - Extensible framework, integrated components





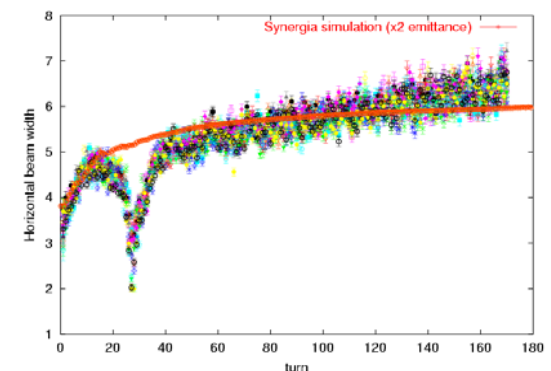
FNAL participation timeline

- End of 1999 proposal writing for new initiative (PGS)
 - targeting future technologies (muon collider)
- FY2000: \$60k bridge funds -> 2 students for space charge in cooling channels
- End of 2001: SciDAC funding, new hire beginning of 2002. Focus on
 - Space charge effects in circular accelerators
 - code integration, framework development, etc
 - ⇒ introduced modern software techniques
 - ⇒ **Synergia** package
 - Machine data/Model comparisons



1PE: 500 particles, 460 sec

128 PE: 500,000 particles, 4400 sec





Synergia team objectives

- Acquire expertise in parallel beam dynamics codes
 - both for design and operational issues
- Create Beam Dynamics package with the ability to model collective beam effects in 3D
 - Utilize power of parallel computing
- The code should
 - Integrate/utilize existing packages
 - Be easily distributable & portable
- Compare code predictions to machine data



Synergia team objectives, con't

- We would like to make our package
 - easy to distribute on specialized machines & commodity PC clusters
 - build system, code distribution and versioning system
 - easy to use: documentation, human(e) interface
 - easy to “build” using the package
 - clear interfaces so users can add new modules
- Would like to use both on operating machines & design
 - use on present machines: research and a reality check
 - maintain balance between development and “every-day” operation
 - and try to be realistic: catalog size/importance of different effects. Too many parameters to control in data/MC comparisons...



Achievements To Date

- First fully 3D parallel space-charge code for circular accelerators with multi-turn injection capabilities.
 - Re-use existing beam dynamics packages, [mxyzptlk](#) & [Impact](#). Utilize [split operator technique](#) and include particle manager utilities
 - Provide build system and code distribution tools
 - Human(e) interface & standard accelerator lattice description (MAD)
 - Model FNAL Booster (a reasonable first choice for space charge studies, even before the DOE recommendation...)
 - [Develop analysis software for both machine and simulated data. Machine studies and instrumentation calibration.](#)



http://cepa.fnal.gov/psm/aas/Advanced_Accelerator_Simulation.html



Status/Plans

- 3 year SciDAC funding (~\$350k) cycle ends at FY04
 - Finish development of space-charge package, with emphasis on code modularization. **SBIR will provide help of 1FTE × 6 months.**
 - Compare Synergia against other codes
 - **Have conclusive results on Booster space charge effects @ injection (publish)**
 - documentation, distribute code (already have candidate users)
 - proposal writing for next initiative (work starts this summer)
 - Would like to include other physics modules (beam-beam, etc)
 - **prerequisite code modularization, framework development**
- ⇒ Would like to strengthen data/model comparison effort



Future plans/Issues

- Available manpower NOT sufficient for **code development** plus **expansion of physics capabilities** AND a coherent **experimental program**. Help is needed for
 - taking data (machine studies) at regular basis and storing and analyzing data using our analysis tools
 - running simulations and participate in data/model comparisons
- Why do we need to expand physics capabilities?
 - **we need local expertise on any simulation tools needed for either new designs or present machine operation**
 - Tevatron, LHC, LC, advance acceleration techniques
 - faster turnaround and control of the studies



Plans/issues (short term)

- Implementation will maintain current Synergia philosophy
 - re-use existing physics modules (beam-beam module developed at LBNL for example)
 - user friendly interface and MAD lattice description
 - portability to different platforms
- Couple such development to machine studies
- Additional manpower to do analysis and data-simulation comparisons.
 - post-doc or Computer Scientist
 - Grad student(s) (from the BD PhD program ?).



Potential future projects; emphasis on computation requirements

- **Beam-beam effects** both weak-strong and strong-strong (Tevatron, collisions at LHC)
- **Electron cooling** (recycler, ...)
- **Electron cloud effects** (LHC, ...)
- 3D, multi-parameter **electromagnetic modeling** (rf structures for LC, ...)
- **Plasma acceleration modeling**
- ➡ Integration: multi-physics, multi-species simulations which include collective effects!
- ➡ Computational support issues associated (code maintenance, distribution, documentation, validation, etc)



Table 1. A (non-inclusive) summary of modeling needs for Run II and beyond, with emphasis on high-fidelity accelerator modeling. The highlighted packages are codes developed under SciDAC funding by the "Advanced Accelerator Modeling" collaboration. The packages marked with † have capabilities needed for a self-consistent multi-physics, multi-particle dynamics capable code, and should be integrated to a single framework.

Projects	Physics Process	Package	Comment
Proton Driver (Booster & upgrade options)	Space-charge	Synergia †	3D/framework
		Orbit	2.5D-3D(inefficient)
		ML/Impact	3D
	Single particle optics (relevant to all other options)	Mxyzplk †	libraries
		MAD (version 8)	Frozen but trusted
		ESME	1D longitudinal
		Transport, Turtle	Should be phased out
Tevatron	Beam-beam	LBNL, SLAC †	3D, private
		FNAL	2D, private
	Intra-IBS, residual gas	FNAL †	private
Run II Tevatron complex (e.g Recycler)	Electron cooling	FNAL †	2D, needs 3D
LHC	Beam-beam	See above	
	Electron cloud	USC †	3D, private
NLC	Electromagnetics	TAU3P, OMEGA3P	3D/framework
		MAFIA	Insufficient accuracy



Summary

- CD expertise, **complementary (at least in emphasis) to BD**, for accelerator modeling
- There is a need for **high performance computing** in future R&D projects; also a need for **modern infrastructure** in such simulation efforts
- CD could provide **external fund leveraging** (SciDAC and ScaLeS) and will benefit in obtaining such funds from expanded projects
- **Planning and coordination with BD needed**, to define projects and appropriately use the strengths of its constituent